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MAGNETORESISTANCE AND SUPERCONDUCTIVITY FOR APPLICATION TO DC TO AC CONVERSION

SEMI-ANNUAL STATUS REPORT

PR-49

OTS PRICE
XEROX $ 1.60 ph
MICROFILM $ 0.80 mf

by

Richard Bechtel
W. W. Grannemann

December 1963

This work performed for
National Aeronautics and Space Administration
Grant NsG 279-62

2 ENGINEERING EXPERIMENT STATION

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~~University of~~ New Mexico U.

Albuquerque, ~~New Mexico~~

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1.0 Introduction

A

There are no significant experimental results to report at this time for the superconductivity program due to unfortunate delays in the construction of the special dewar needed for these experiments. The difficulties that have caused these delays have, hopefully, now been ironed out and delivery date has been set for the first week of February. While waiting for the dewar, considerable effort has been directed toward assembling a number of test samples designed to deliver a maximum amount of information in a minimum test time. An attempt has been made to outline experiments that will determine the feasibility of the superconducting-switch convertor.

Some of the factors which must be determined are: (1) the switching time for various wire materials, wire configurations and thinfilms (2) liquid helium dissipation in the normal state (3) maximum current for all samples (4) maximum magnetic fields for all samples (5) and contact effects for the various bonding techniques and contact materials that were employed in constructing the samples.

A discussion of the techniques through which the samples described herein were constructed will be reserved for a follow-up report which will be submitted shortly after the dewar is obtained and the preliminary experimental results are in.

2.0 More on the MR Convertor

A simulated single-branch convertor will be set-up using the various corbino disks described further on. This will be done at liquid helium temperature and, possible, at room temperature. For the room temperature experiment InSb corbino disks will be employed.

These simulation experiments will be conducted with a sinusoidal magnetic field of about 1000 gauss using a small AC electromagnet constructed by this laboratory. The output will be observed on an oscilloscope connected across a load resistance. Of course, only a small magnetoresistance ratio can be expected at this low field, thus, the circuit resistance will have to be extremely low in order that the effect of the small resistance change of the MR device can be detected and analysed. For the room temperature runs this should be no problem since very large copper buss can be used. However, for the liquid helium experiments where a small capacity dewar is used one must be careful in the use of copper because of its high coefficient of thermal conductivity.

Plans are underway for a larger AC electromagnet capable of producing a 10K gauss AC field for future experiments along this line.

3.0 Proposed Cryogenic Experiments (4.3°K)

3.1 Experimental Apparatus

3.11 A special rectangular tail dewar, shown in Figure 3.1 in position in the electromagnet, will shortly be available for the liquid helium experiments. The tail section has a 7/16" x 3 1/8" x 10 3/4" long interior working region and is 1 1/8" thick on the outside, and is made entirely of non-magnetic materials. These dimensions will provide a minimum gap in the electromagnet of 1 1/8" which will allow a maximum magnetic field of about 13,000 gauss using 2 inch tapered pole pieces.

The dewar will be suspended in a three-leg, steel mount which is adjustable vertically through the full range that the tail section will allow. This feature will aid in lining up the desired working region with the magnetic field region.

Support equipment on hand for the dewar consists of a 25 liter liquid nitrogen shielded liquid helium container, a vacuum shielded transfer tube, a 25 liter liquid nitrogen container, and a liquid helium level indicator. In addition is helium gas pressurization equipment to be used in transferring the liquids.

3.12 In order to obtain an AC magnetic field, two Helmholtz coils have been wound which fit over the poles of the electromagnet. These coils are shown in position in Figure 3.1. They are to provide a modulating field of about 1000 gauss and will be driven by a 60 cycle 220 v supply. The scheme here will be to set the DC field just below the critical point and then transend between the superconducting and normal state, alternately, with the AC field. This will provide some indication of the switching response of various wire forms and wire materials.

3.2 Magnetoresistor Experiments at $4.3^{\circ}K$

Several samples have been prepared for analysis at liquid helium temperature. These were designed both to uncover new material compositions for MR devices and to improve the response of standard MR geometries. The various sample configurations are shown in Figure 3.2; and a discussion of each sample is presented below.

A. This sample is a 1 3/8" bismuth corbino having niobium contacts which will be superconducting at $4.3^{\circ}K$. It was designed to determine the effect of eliminating the IR drop in the circumferential contact to result in a more uniform E field. Whether this modification will enhance or lessen the MR response will be of interest.

B,C. These samples are of bismuth. The former is a geometry that was previously tested, using InSb, at room temperature and found to have a MR ratio which compared closely with the corbino disk.[1] The latter has a slight modification in that one leg has been extended to further distort the E Field.

[1] B. J. Harper, R. Bechtel, W. W. Grannemann, "A Study of the Hall Effect and Magnetoresistance for Low Voltage, High Current, DC to AC Conversion," EE-96, UNM Technical Report.

D,E. These samples are 1 3/8" diameter bismuth corbino disks with copper contacts, the former with a 1/16" diameter center contact and the latter with a 1/2" diameter center contact. They will be used to determine the MR ratio dependence on the degree of the center contact area. The motive here is to disclose what the limits are toward increasing the current carrying capability of the corbino by increasing the center contact area.

F,G,H. These three samples are bismuth rectangular bars 1 5/8" L x 11/16" W x 1/16" T. The first has no Hall shunt, the second has a copper shunt, the third has a lead (superconducting) shunt. These will be used to further explore, over more complete extremes, the effect of shorting the Hall voltage in improving the magnetoresistance.

I. This sample is a lead corbino disk with niobium contacts. Since lead has a lower critical field than niobium, it can be switched in and out of the superconducting state while the niobium remains superconducting. It is hoped that the normal state resistance will be increased through a magnetoresistive effect in the lead. This would result in a higher switching ratio while keeping the sample size compact.

The above samples will be tested in both a DC magnetic field and a modulated magnetic field. The latter experiment will be conducted in an effort to determine how fast a magnetoresistor can be switched. This will be done, initially, by modulating the DC magnetic field with the 60 cycle one kilogauss field.

For the material study, six corbino disks have been constructed for evaluation at liquid helium temperatures and consist of Pb-In (10%), Pb-Bi (10%), Bi-In (50%), Pb-In-Bi (80%-10%-10%), Pb-InSb (50%), and Pb-InSb (10%).

3.3 Superconducting Experiments at $4.3^{o}K$

A sample holder has been constructed for testing short lengths of superconducting wire and is shown in Figure 3.3. This holder will be used primarily for high current measurements to establish a check with theory of critical currents and magnetic field for various wire and wire size. It will also be used for some switching time experiments to compare straight wire and coiled wire results.

Two coils have been wound, on reusable coil forms (Figure 3.4), one of which will be used to compare experimental results with those calculated from theory.[2] This coil was wound on a plastic form using 13 feet of 20 mil niobium wire, and

[2] B.J. Harper, R. Bechtel, W. W. Grannemann, *Op. Cit.*

occupies a 1 3/4 x 2 inch area. The wire is connected to heavy copper lead-in wire for high current capability. The other coil consists of one foot of 20 mil Nb-15% Zr wire. This coil will be used as a standard since considerable data has been published for Nb-15% Zr.

A thin film of niobium and a thin film of lead vapor-deposited on glass substrates will be used to initiate a feasibility study of thin films. Low resistance cement was used as an electrical contact to the films. The suitability of this cement material as a contact medium will also be of interest.

4.0 Superconducting Switch Feasibility based on Review of the Field

1. Feucht and Woodford [3] have calculated transition time measurements using a superconducted radio-frequency mixer. This device uses a thin film of high-purity tin evaporated as a glass substrate which is sandwiched between two pieces of polystyrene which has loop contacts of lead embedded in them. Around the unit is wrapped a switching coil to which a radio-frequency local oscillator signal is fed. With this configuration it was determined that the time required to switch the film in and out of the superconducting state was as short as 0.625×10^{-9} seconds.

2. Buck [4] describes a device called a "Cryotron" designed as a potential computer component. It consists of a control winding of 0.003 inch niobium wire wound around a 0.009 inch tantalum wire. The niobium winding serves as the control gate which switches the tantalum wire in and out of the superconducting state. In this manner a small current is made to control a large current. The transition time of the cryotron is primarily regulated by the L/R time constant of the device to a limit determined fundamentally by relaxation losses. An

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3 D. L. Feucht and J. B. Woodford, Jr., Journal of Applied Physics, 32: 1882, (1961)

4 D. A. Buck, Proceedings of the IRE, 44: 482, (1956)

estimate of this limit is between 100 and 1,000 megacycles. However, the L/R time constant for these small devices places the transition time in the 10^{-3} second range.

3. Young[5] has described a so-called "crossed-film cryotron" which uses a tin-film gate crossed by a lead control film. This device is interesting since it offers a larger resistance in the normal state than does the wire cryotron, thus offering lower transition times.

From the foregoing it would seem one could be quite optimistic about the superconducting switch converter for application where the frequencies are less than 1,000 cycles.

5 D. R. Young, "Recent Developments in High Speed Superconducting Devices", Brit. J. Appl. Phys., 12, 359, (1961)

5.0 Status of the Theory of Superconductivity

5.1 Since the time when Kamerlingh Onnes first discovered the phenomenon of superconductivity in 1911 a complete theory for it has been sought, a microscopic theory from which there could be derived from first principles the regularities in the appearance of superconductivity as noted by Matthias.[6] The principle of these regularities are as follows:

1. Superconductivity has been found only for those metallic substances having between about 2 and 8 valence electrons.

2. Where transition metals are concerned, the variation in the critical temperature with the number of valence electrons shows sharp peaks for this number equaling 3, 5, and 7.

3. For a given number of valence electrons, certain crystal structures appear more favorable than others. Too, the critical temperature increases with a high power of the atomic volume and inversely with the atomic mass.

Unfortunately, the present understanding of superconducting and normal metals is still far from this goal. In fact, there is still an inability to calculate the actual

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6 B. T. Matthias, Progress in Low Temperature Physics, Vol. II, Interscience, (1957)

critical temperature of any superconductor. However, there have been several qualitative theories proposed which to some degree describe the properties of at least an ideal superconductor. One must realize the difficulty of the problem which lies in the extreme smallness of the energy involved. For, at absolute zero, the energy gap between the superconducting and normal phase is on the order of 10^{-8} ev per atom; whereas, for a normal metal the Fermi energy of conduction electrons is on the order of 10 to 20 ev.

5.2 One of the most successful theories is the one postulated by Bardeen, Cooper and Schrieffer -- the so-called BCS theory. This theory accounts for all the main facts of superconductivity which are (1) a second-order phase transition at the critical temperature, (2) an electron specific heat varying as $\exp(-T_c/T)$ near absolute zero, and other evidence for an energy gap for individual particle-like excitations, (3) the Meissner effect of zero magnetic induction in the superconducting state, (4) effects related to infinite conductivity and (5) the dependence of the critical temperature on isotropic mass.

The BCS theory considers that the basic interaction accounting for superconductivity lies with a pair (as opposed to single electron-phonon interaction) of electrons through an interchange of virtual phonons.[7] This simply means that the

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7 Virtual phonons are defined as those with very short lifetimes such that, due to the uncertainty principle, it is required that energy be conserved in the process.

distortion of a lattice by a moving electron gives rise to a phonon. Further, the distortion of the charge distribution of the lattice results in a propagating flucuation which in turn affects a second electron some distance away when the wave reaches its location. The conclusion then is that superconductivity occurs when the attractive interaction between two electrons by means of phonon exchange overrules the usual repulsive screened coulomb interaction. In addition the BCS theory formulizes the normal state by the Block model [8] which deals with the effect of the periodic field of the lattice on a single electron.

5.3 A number of possible explanations have been offered to indicate what fundamental effects might limit the speed of transition between the normal and superconducting state. Most of these predict switching times far shorter than what is observed. One suggestion of interest, proposed by Nethercot [9], predicts a longer time, and is derived relatively directly from the BCS theory.

Briefly, Nethercot states that the present explanation is based on the switching speed being limited by a spatial rather than purely time limited (temporal) effects. That is,

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8 L. Brillouin, Wave Propagation in Periodic Structures, Dover, (1953)

9 A. H. Nethercot, Jr., "Superconducting-Normal Transition Time," Physical Review Letters, 7, 226, (1961)

at fast switching speeds (high frequency) the skin depth becomes so small that this thin layer cannot change its state due to the large adjacent volume of unswitched material. Therefore, it doesn't seem reasonable that these skin depths could change state in times on the order of 10^{-10} seconds since it can be expected that the properties of the film would be considerably altered by the adjacent material.

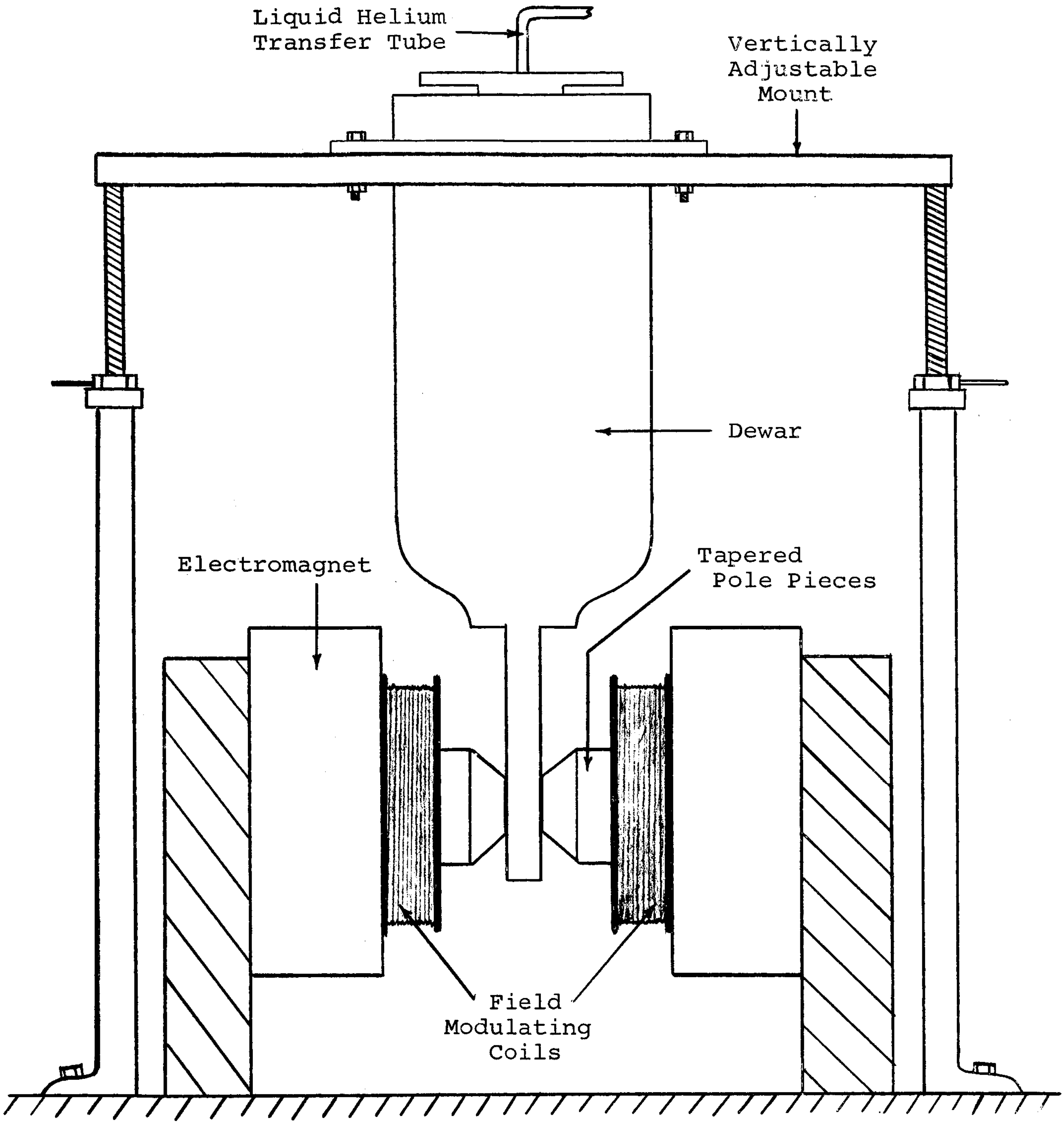
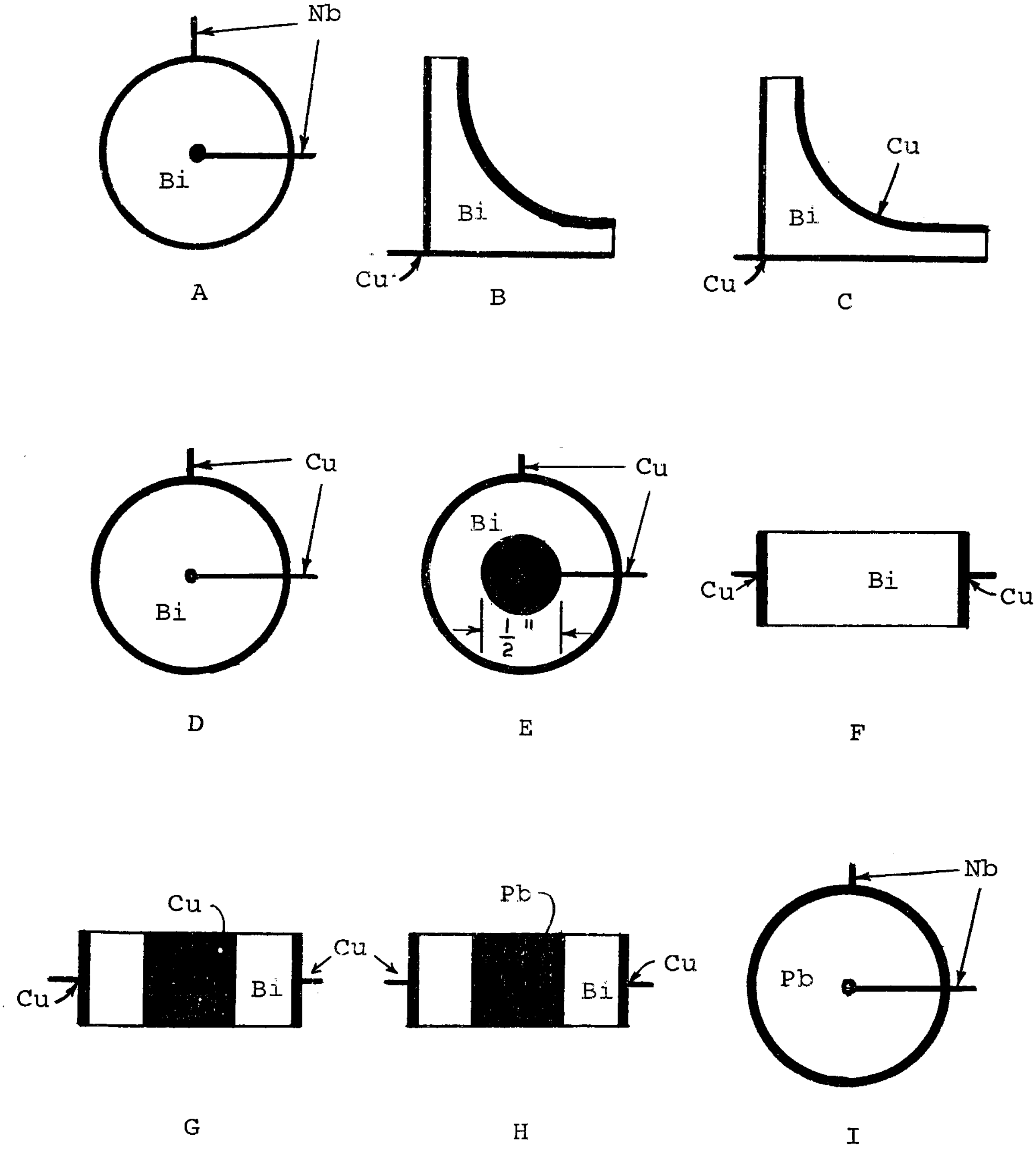

Liquid Helium
Transfer Tube
Vertically
Adjustable
Mount
Dewar
Electromagnet
Tapered
Pole Pieces
Field
Modulating
Coils

Figure 3.1



Nb
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Cu
B
Cu
Bi
Cu
C
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Bi
D
Cu
Bi
1/2"
E
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F
Cu
Cu
Bi
Cu
G
Pb
Cu
Bi
H
Nb
Pb
I

Figure 3.2

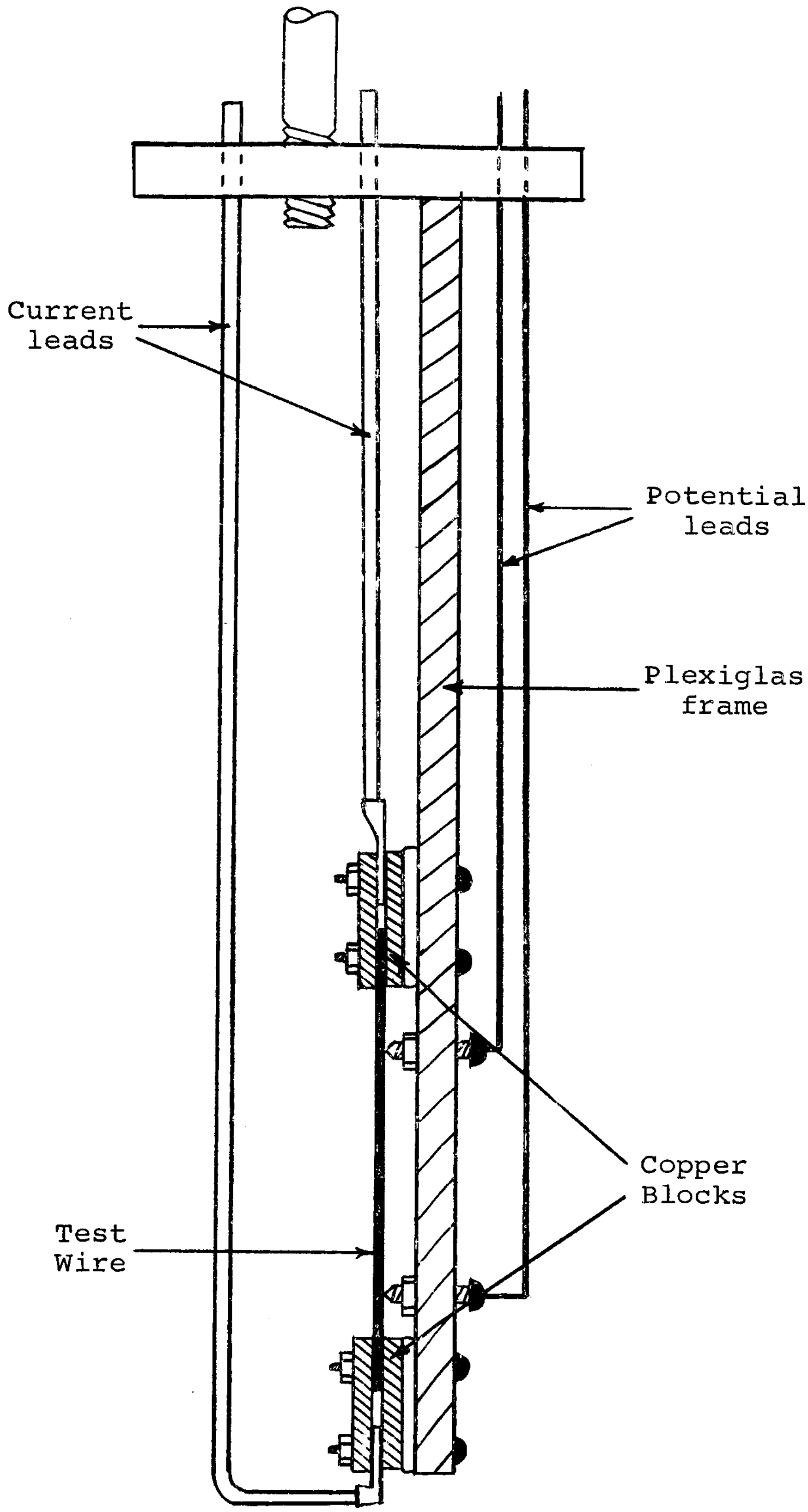
Current
leads
Potential
leads
Plexiglas
frame
Copper
Blocks
Test
Wire

Figure 3,3

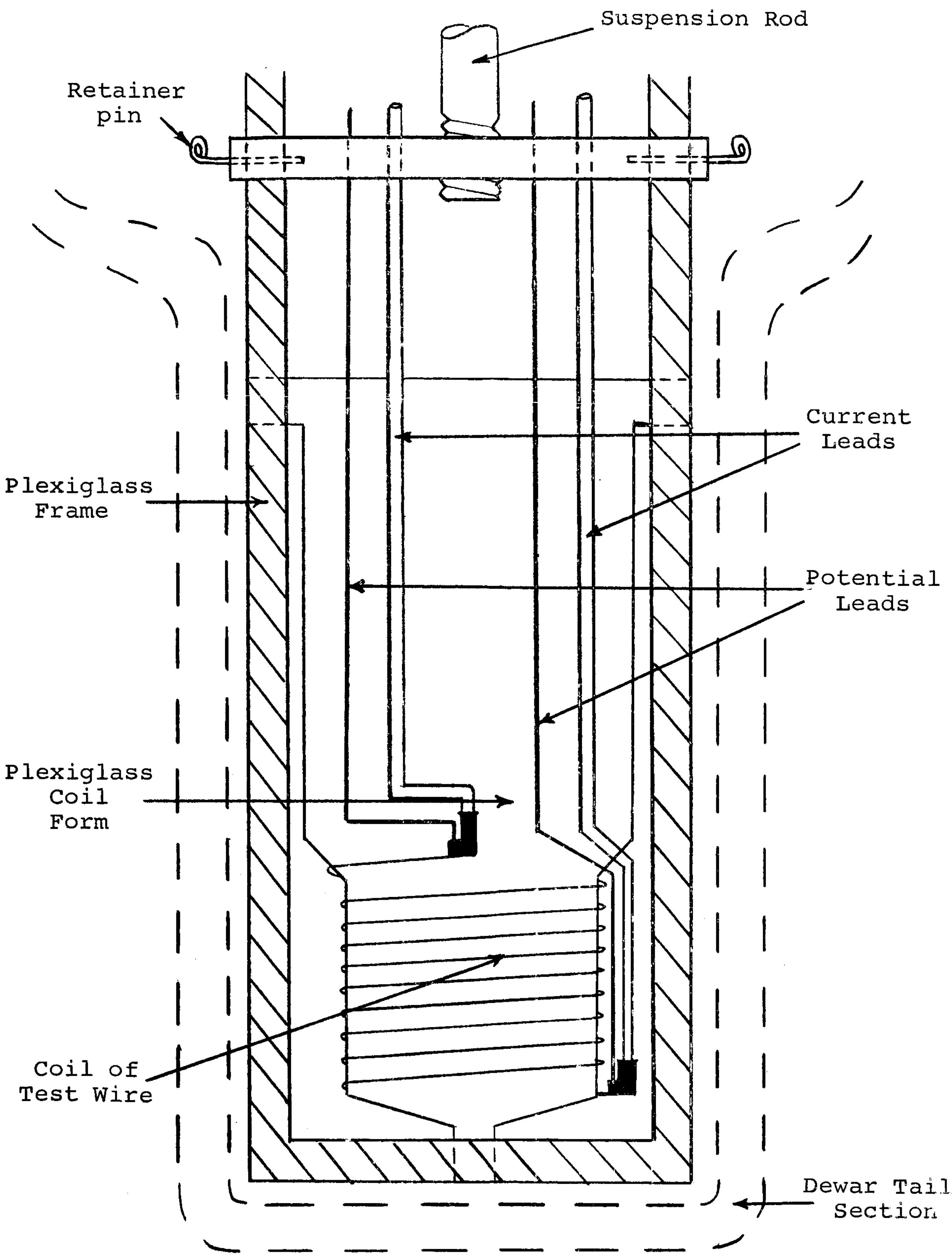
Suspension Rod
Retainer pin
Current Leads
Plexiglass Frame
Potential Leads
Plexiglass Coil Form
Coil of Test Wire
Dewar Tail Section

Figure 3.4